Modeling and Analyzing the Propagation from Environmental through Sonar Performance Prediction

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LONG-TERM GOALS

Central to the long term goals of this joint project is to understand the physics of the propagation of uncertainty through the interfaces between oceanography, acoustics, array processing and performance prediction. We will develop an efficient overall simulation platform that combines all of the components of the baseline (mean) and uncertainty problem: Oceanography through 4-D acoustic field prediction. The development of a methodology to distill the complexity and uncertainty of the ocean acoustic environment and the system level sensitivities to relevant situational awareness for the operator is an important goal of this research.

This project is a joint effort as summarized in the team report. Below we concentrate on the SIO effort. A substantive part of the SIO effort is a joint research program with the SAIC component involving the application of the adjoint methodology to ocean-acoustics. This part of the effort is contained in the SAIC report.

OBJECTIVES

The objective of this research program is to both develop a methodology to predict uncertainty in the whole performance prediction process and to understand the uncertainty physics of the individual components of the process. The latter provides the potential to develop methods to reduce uncertainty. We intend to follow a two pronged approach: (1) total model development for Monte Carlo simulation and (2) studying the physics of the interfaces between oceanography, acoustics, array processing and performance prediction.

APPROACH

We intend to follow a two-pronged approach: (1) total model development for Monte Carlo simulation and (2) studying the physics of the interfaces between oceanography, acoustics, array processing and performance prediction.

Our integral part of our approach to the total uncertainty simulation model development will depend on the usual Monte Carlo runs to convert an ensemble of oceanographic states to an ensemble of system output showing the range of possible values. This method has the advantage of retaining validity in the presence of strong nonlinearity, as well as being computationally simple. The ocean ensemble will be coupled to a wide area acoustic propagation model and an accurate array processing model for the purpose of performing area wide performance prediction with an uncertainty measure. Particular care will be given to the mode of representing this information to the operator.

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14. ABSTRACT

Central to the long term goals of this joint project is to understand the physics of the propagation of uncertainty through the interfaces between oceanography, acoustics, array processing and performance prediction. We will develop an efficient overall simulation platform that combines all of the components of the baseline (mean) and uncertainty problem: Oceanography through 4-D acoustic field prediction. The development of a methodology to distill the complexity and uncertainty of the ocean acoustic environment and the system level sensitivities to relevant situational awareness for the operator is an important goal of this research.

15. SUBJECT TERMS

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We also intend to explore linearized methods for determining system response ranges, based on an analogy to the tangent linear model and adjoint model techniques in use in Physical Oceanography. Applying these concepts to the acoustic codes may provide a computationally efficient way to compute sensitivities and transform ocean state uncertainty covariances to system performance uncertainty covariances. It may be that only an idealized reduction of the problem (as set-up in 1) is attempted, depending on the difficulties that are uncovered. Further, it is hypothesized that this approach may be more applicable to the total problem rather than stopping at the acoustics output because, to a certain extent, performance prediction is somewhat of a "smoothing" process, possibly enabling the required linearization mentioned above. We consider this part to be a high-risk high-payoff idea, in that to our knowledge, the oceanographic data assimilation adjoint approach has never been applied to acoustic models, much less to the whole performance prediction process. Part of this work is contained in the SAIC report. The component concerned with associating acoustic array processing such as Matched Field Processing with the adjoint methodology is reported here.

Uncertainty occurs in the geometry (source/receiver locations, bottom depth), the bottom properties, the surface properties (sea state and resulting bubble clouds and surface roughness), and the ocean volume (internal waves/tides, meso-scale features such as eddies, and fronts). The uncertainty of many of these is easy to characterize. For instance errors in receiver locations are a function of the performance of depth-heading sensors on the arrays; their performance may vary over time on a given array but by and large there are no interesting scientific issues about their accuracy. The most interesting and perhaps important of the above listed uncertainties, is that due to the oceanography and how it subsequently regulates acoustic bottom interaction with uncertain geophysical parameters.

The ROMS primitive equation model will be used to simulate the small-scale features in an area of interest. Separately, a simpler internal wave model will be used to characterize the space-time structure of the internal wave field that will be excited using a uniform energy density of internal waves. In an operational scenario, we envision that one or the other of these models will be used to predict the statistics of the oceanographic variation. The primitive equation model is not viewed as a tool that would predict a deterministic environment but rather as something that might provide a more accurate prediction of the typical variation. The 1-D internal wave model is obviously simpler and computationally more practical, but may be less accurate. One objective will be to compare the relative merits of the two approaches.

The existing acoustic models produce a realization of the pressure field for a single deterministic environment (which is obviously distinct from a mean field). To capture the uncertainty the acoustic models will need to be enhanced to rapidly produce an ensemble of pressure fields or statistics of the ensemble. The algorithmic approach we will develop in this program is different in each of the 4 standard model types. However, the common starting point for all of these is the "environmental endpoints," i.e., the limits (or, more precisely, variances) characterizing the uncertain environment. Despite the variety of sources of uncertainty, they can all be treated using the same framework as will be discussed below. To fix ideas, imagine a mean sound-speed profile and a lowest-order EOF characterizing the variation due to the first baroclinic mode. The "environmental endpoints" are the mean with that EOF added and subtracted based on the excursion seen in the oceanographic data. If the internal wave model is found to be adequate, it will be integrated with the acoustic model so that an input SSP is used first to drive the internal wave model, and then passed directly to the acoustics model along with the environmental endpoints calculated by the internal wave model. {This work will be done with the SAIC group.]

We also expect to use the tools that we have developed to study the viability of: (a) assimilation of acoustic data from ships of opportunity; this might involve data fusion with remote sensing or the use of battlegroup location via netcentric operations and (b) optimizing ASW area coverage in a way that reduces uncertainty by accumulating and assimilating data during operations.

Throughout the program, we will have as underlying theme and goals, the construction of a methodology for capturing uncertainty in performance prediction from the overall system perspective. The focus of this work will be distilling the complexity and uncertainty of the ocean acoustic environment and the system level sensitivities to relevant situational awareness for the operator. [Cox will lead/coordinate this aspect of the program].

WORK COMPLETED

We have configured and run the ROMS model for the Southern California Bight (SCB) region, embedding higher resolution grids within the domain of the lower resolution grid which has been run to simulate and assimilate the CalCOFI data. The nesting is one way at the moment, with the boundary conditions of the inner grid taken from the larger-scale model.

The formulation of the adjoint model for the Parabolic Equation acoustic model has been completed and a paper has been submitted. This work, done with the SAIC group is contained in their annual report.

However, for the purpose of better, understanding the adjoint/acoustic problem we have also derived a method for inverting one to three-dimensional sound-speed perturbations in stratified waveguide environments over ranges of several kilometers, without the need for extensive numerical spatial integration. Typically, adjoint problems involving the wave equation require that the difference between a measured and modeled field be numerically backpropagated through the acoustic environment, and then this backpropagated field must be numerically correlated with the original forward modeled field to produce an estimate of the error surface gradient, or "Frechet derivative." For the particular case of a range-independent ocean perturbation, a means of eliminating the numerical backpropagation and correlation steps was found to obtain a direct relationship between the Frechet derivatives and the normal modes of the baseline acoustic environment. This approach can be extended to three-dimensional (range-dependent) waveguide perturbations as well.

RESULTS

Figure 1 shows topography (plotted in color) for 3 levels of nested models, showing the outer grid we have been running for CalCOFI predictions (9km resolution), our new 3km grid we developed for this project, and a 1 km finer grid that was created using new UCLA tools. The 3 km resolution domain has been driven with high-resolution winds downscaled from NCEP analyses using a regional spectral model (RSM) developed by the ECPC at SIO. The goal has been to reproduce observations taken in the Santa Barbara Channel (SBC) and Santa Maria Basin (SMB) by SIO and others as part of an Minerals Management Service (MMS) study focused on understanding the fate of oil spills in the region. The RSM winds have been compared with the original NCEP winds as well as moored wind measurements in the SBC and SMB, and the 3 versions show substantial differences. The efforts at comparison have highlighted the uncertainty in the ocean driven by uncertainty in the wind products, and the realism of the runs are still being improved. At the same time, ocean realizations from both the 3-km and 9-km resolution models have been used to examine the acoustic variability of the region, in cooperation with Orincon Group. The time evolving temperature and salinity fields from the model are

converted to sound speed and used to run a variety of acoustic models and quantify the variability in the propagation.
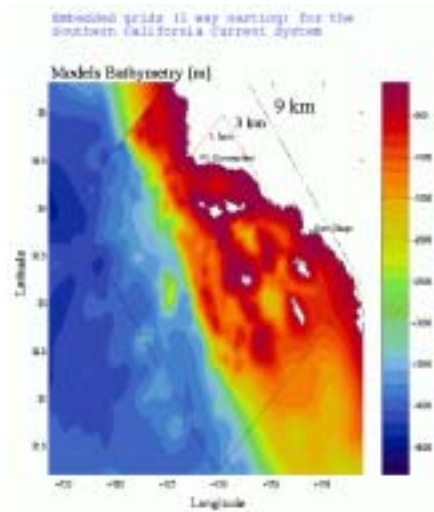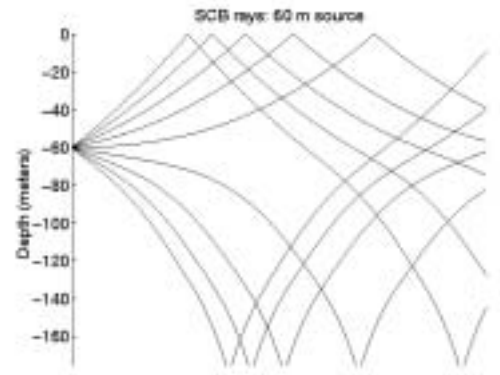

Figure 1. Topography for models.

Figure 2. Ray paths.

Figure 2 shows an example of rays paths for a point on the continental shelf in the SMB, showing the effects of a surface duct in the upper 60 m with downward-refracting conditions below. The goal is to convert uncertainty in the winds and initial conditions to uncertainty in the model state, and then to uncertainty in the acoustic propagation. In collaboration with the Duke team members, these uncertainties will be converted into uncertainty in performance measures.

Figure 3 illustrates a comparison between the two-dimensional error surface gradients generated by numerical differentiation of a finely-gridded error surface, subplot (a), and the new adjoint method, subplot (b). The error surfaces are "least-square" surfaces, and the two inversion parameters are the waterborne and bottom sound speeds of a Pekeris waveguide. The simulations are for a 20 Hz source placed 2 km from a 48-element array centered in a 100 m deep waveguide. Both plots show contours of the original error surface for comparison. It is seen that the adjoint computations successfully reproduce the error gradient (Frechet derivative) out to water and bottom speed mismatches of at least 15 m/sec.
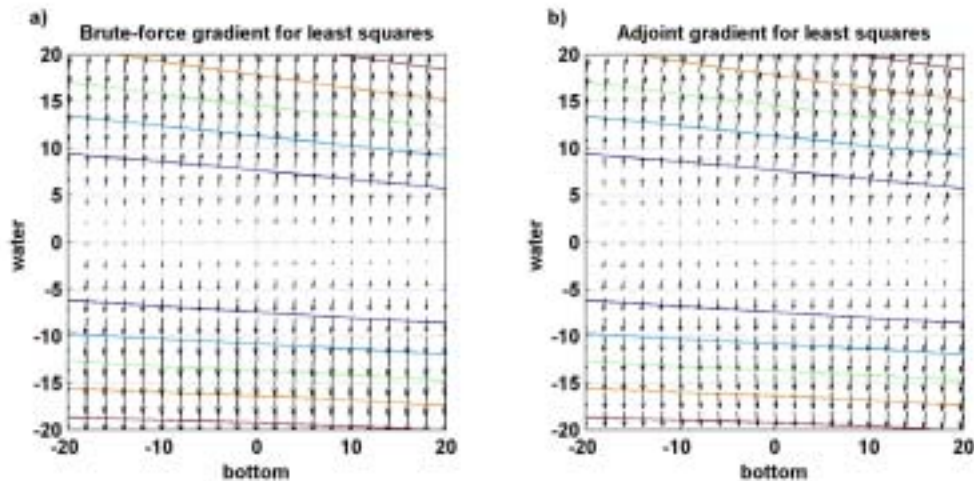

Figure 3. Error surface gradients.

IMPACT / APPLICATIONS

This expected impact of this project is to provide a methodology to provide a reliability measure to the operator of at-sea performance prediction models.

TRANSITIONS

No transitions took place in FY02.

RELATED PROJECTS

This is one of the programs in the ONR UNCERTAINTY DRI.

PUBLICATIONS

P. Hursky, M. B. Porter, B. D. Cornuelle, W. S. Hodgkiss, and W. A. Kuperman, "Adjoint-Assisted Inversions for Shallow Water Environmental Parameters," in *Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance* Eds: Nicholas Pace and Finn Jensen, Boston: Kluwer Academic Publishers, 2002. [ISBN 0-4020-0816-3].